AfrikaBot: Design of a Robotics Challenge to Promote STEM in Africa

Abstract* - Science, technology, engineering and mathematics education for high school learners in developing countries is a challenge for two significant reasons: equipment for education is expensive and complex, and economically-marginalized youth must be integrated in pre-engineering programs to prepare them for technical programmes at university. The goal of establishing AfrikaBot is to prepare high school learners to study engineering at the University of Johannesburg; thus to train teenagers from disadvantaged communities with no prior experience in STEM to participate in a challenge to build and program a robot. Also, AfrikaBot aims to equip teenagers from low-income households with technology and entrepreneurial skills in a repressed economy. AfrikaBot achieves the above with a build-it-yourself robot that can be used after the competition to invent systems with real world applications. Anticipated long-term outcomes of the AfrikaBot program will influence the structure of future robotics challenges, and promote a higher number of technical candidates from marginalized communities. By transferring enabling technology skills in a fun and engaging way, participants will rapidly build the confidence to pursue careers in STEM fields. Participants can also acquire entrepreneurial skills that may lead to the establishment of new businesses and the creation of local jobs in both the formal and informal sectors in Africa. This paper presents the organizational and physical design of AfrikaBot, a robotics challenge that will be held in the latter half of 2016.

Keywords — (*Robotics, STEM, AfrikaBot, Entrepreneurship*)

I. INTRODUCTION

Science, technology, engineering and mathematics (STEM) education poses a problem in schools and colleges around the world due to the complexity and cost of equipment. In Brazil, tests have been made with simulated robot soccer to expose more teenagers to STEM outreach opportunities [1]; but previous work concurs that physical robots hold unique appeal to teenagers in outreach programs [2].

In developing countries basic needs such as water, sanitation and power take priority, funding for pre-engineering programs in South African high schools often comes from private companies, and as in the example of AfrikaBot where funding support came from professional associations like the South African Institute of Electrical Engineers (SAIEE) [3]. To implement an educational program with hardware, funds must be applied cost-effectively but with no compromise. AfrikaBot promotes interest in STEM subjects and meets the affordability and accessibility requirements of a developing country.

In Africa, the ten dollar robot design challenge was launched to promote STEM activities in poorer communities [4]. AfrikaBot is designed to cater for economically disadvantaged teenagers with no experience in STEM related activities, but also offers an exciting challenge for wealthy teenagers, undergraduate engineering students and entrepreneurs looking for a commercial platform.

The AfrikaBot is a microcontroller-based robot that can be programmed with easy graphics or BASIC text code which is more advanced and allows more possibilities than graphical programming. The competition consists of a maze 1000mm by 2000mm with a start and end point, and an electronic timer that is triggered by laser beams. The tunnel, through which the robots must move, acts as a size limit on the robots to prevent participants from building large and expensive robots and thereby gaining an unfair advantage in the competition.

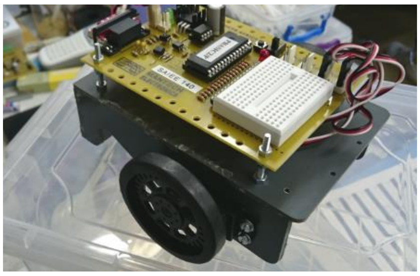

Figure 1: The AfrikaBot robot

All robotics hardware and software combinations are permitted, but the equipment for the outreach program was selected based on the availability of an easy-to-use free graphical user interface (GUI) for participants with no programming experience. There is also a free one-step text code integrated development environment (IDE) text editor for advanced users.

An effective STEM outreach requires more than just a cost effective hardware kit and easy-to-learn software: it must also include online training resources and be supported by a community of educators [5]. AfrikaBot is the result of the RobotScience project, an eight year effort to make robotics more accessible to South African teenagers. During this time significant strides were made to establish an extensive website, a Youtube channel [6] and a growing network of supporting educators. Historically, mobile robot-based competitions in South Africa have been organised around the excellent Lego platform, but the rules did not allow other types of robots [7].

II. OVERVIEW OF AFRIKABOT

In 2000 one of the founders of the RobotScience project returned from the United States of America (USA) and tried to teach basic electronics at a shelter for teenagers. The project was unsuccessful due to the theoretical and abstract nature of electronics. De Christoforis [8] found that “Students’ learning significantly improves when they are actively involved in building something meaningful to themselves.” A small desktop-scale robot called the Boe-Bot [9] was imported from Parallax in the USA to gauge the interest of learners.

In the RobotScience project, introducing an element of electronics that is not possible in other challenges, the learners can build the robot themselves starting with an unpopulated rapid prototyping printed circuit board [10]. In 2012 a pilot project held at Sci-Bono Discovery Centre in Johannesburg, South Africa determined that economically disadvantaged teenagers could build the robot. In 2014 the Shuttleworth Foundation [11] funded another group of learners to build the robots at University of Johannesburg TechnoLab [12].

The AfrikaBot competition was officially announced in 2015 with the first semi-final scheduled for August 2016 and the final scheduled for October 2016. It is anticipated that between sixty and eighty learners will participate in the event; and that more than 50% of the learners will be from poorer communities.

III. DESIGN CONSIDERATIONS FOR AFRIKABOT

A. *Organisational Features*

AfrikaBot is designed as a cost effective STEM challenge for South African schools with minimal staff required for its management. Teachers and learners are encouraged to organize themselves into high school engineering clubs; private companies and industry association members are encouraged to assist with training the participants.

The RobotScience project received funding when the SAIEE decided to support the AfrikaBot challenge in 2015 with their ‘Pay it Forward’ campaign that aims to support young people towards a career in engineering. The SAIEE support enabled the purchase of twenty notebook computers which enabled travel to township schools, as well as fifty AfrikaBot parts kits to construct in the challenge. Currently, advanced security and defense equipment engineering firm Denel Land Systems (DLS) is training twelve engineers who are serving their internship to assist in the implementation of AfrikaBot at a township school in an informal settlement at Diepsloot, Johannesburg [13].

Additional funding was received from First Avenue Investment Management [14] a company that supports the annual First Avenue Institute (FAI) Girls Winter Camp, a week-long partnership between FAI, UJ and the University of New Hampshire (UNH) [15] in the USA. At the camp young women are exposed to engineering activities and field trips which includes a visit to a nuclear reactor [16]; participants are also required to build a robot and enter the AfrikaBot challenge.

The Girls Winter Camp coupled with active recruitment of women into AfrikaBot ensures that the programme addresses the shortage of women in the engineering profession [17]. Continuous approaches are being made to companies that hire engineers to support AfrikaBot.

B. *Physical Design*

The full specification of the maze used in the AfrikaBot challenge is available on the internet as a portable two piece arena that can be moved by one person. The practice maze fits into a passenger vehicle so that it can be moved around with the schools outreach [18]. The compact size of the robots and the transportable maze means the robots can be programmed by township school learners with notebook computers, which has proven more effective than transporting learners to the University. The maze is illustrated in Figure 2.

Where a high school engineering club decides to build a practice maze, when not in use it can be stored vertically against a classroom wall when not in use. An optional wooden surround can be attached to the practice maze to prevent robots falling to the floor and possibly getting damaged.

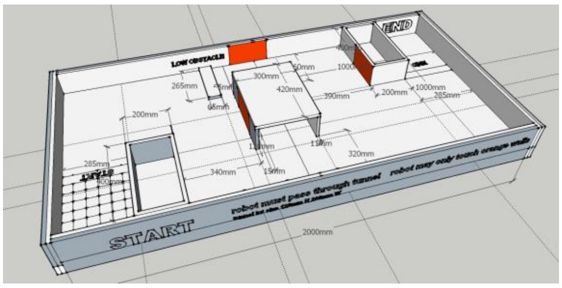

Figure 2: The AfrikaBot maze

Most mobile robotics systems are bought as off-the-shelf solutions with a ready-made controller board. The preferred platform for AfrikaBot is the Parallax Boe-Bot kit which requires no soldering. The AfrikaBot challenge also recognises that “one of the greatest challenges in teaching is that of capturing the interest of the students and cultivating a fascination for learning” [19]. In the RobotScience project learners can build their own electronics control board, and depending on what equipment a school or private individual already has, this can result in a considerable saving. Where participants want to build their own robot electronics, the availability of the Parallax OEM Basic Stamp 2 microcontroller chip [20] offers another option. The OEM 28 pin dual in-line package (DIP) version of the Basic Stamp 2 microcontroller makes home or school assembly possible; and the rapid prototyping control board opens up the possibility of invention and small business start-ups.

The easy-to-program OEM Basic Stamp 2 is a single core eight bit microcontroller that can be abbreviated P1X8. The P1X8 is the smaller brother to the advanced, but more difficult to program Parallax Propeller processor (P8X32), an eight core chip where each processor is 32 bits. The OEM Basic Stamp 2 chip in the DIP package is available at USD $16.99 and is easy to program in PBASIC [21].

The Rapid Prototyping printed circuit board (PCB) costs USD $6.50 without parts [22]. The main design considerations for the rapid prototyping PCB was a clear silkscreen to guide technical novices to solder the parts without error; and provision of mounting points to fit Meccano [23] and Lego [24].

To minimize costs, the PCB is single-sided, and jumper wires connect tracks that need to cross each other without connecting. A rugged DB9 RS232 serial connector is used to link the microcontroller through a USB adapter cable to a laptop computer to download programs to the robot. For the mobile robot, rather than using costly DC motors with gearboxes and costly H-bridge controllers, the most cost-effective solution is continuous rotation servos that combine the motor, gearbox and H-bridge control boards into one compact unit [25].

It was found that the Parallax servo motor wheels with encoder slots [26] do not offer great traction, therefore the O-rings were removed, the nodules clipped off and a rubber "tyre" from a piece of bicycle tube was stretched over the rim to increase grip [27]. Wheels for AfrikaBot can also be made from recycled peanut butter bottle lids and rubber bands [28].

If a learner were to prototype a real-world invention, a small production runs on a kitchen table is possible with the low cost rapid prototyping PCB from Mantech.

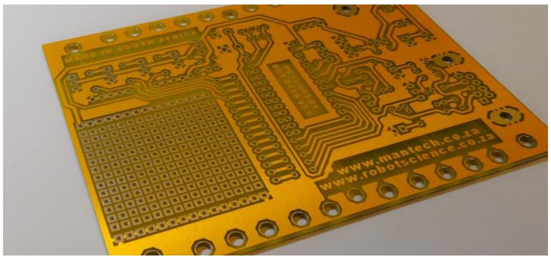

Figure 3: The rapid prototyping PCB

With adequate funding a learner could take the first steps into the world of manufacturing using the OEM Basic Stamp 2 microcontroller. If a learner requires a more powerful microcontroller, the challenging multi core Parallax Propeller chip (P8X32) can be programmed in a range of modern programming languages including C [29].

Battery power for a mobile robot application like the AfrikaBot is costly, requiring six quality AA alkaline batteries to supply the motors. Conversion to rechargeable mobile power requires two 18650 lithium ion batteries connected in series which are affordable at approximately US$2.80 for two, as well as a low cost 18650 type charger for US$3.00 [30].

The RobotScience Youtube channel takes a learner through the process of building the AfrikaBot using a step-by-step approach [31]. To support teachers and learners a swap out repair service is available if the controller does not work once built [32]. The robot is durable, requires no maintenance, and does not usually get damaged if it falls. However, it can easily be repaired if a problem should arise.

Once completed and tested the mobile robot can be programmed to autonomously navigate the maze without any sensors using just the GUI or text software, but for more advanced participants there is an entire range of sensors available from Parallax and other manufacturers. The simplest sensing system that can be implemented is two touch switches can be set up on the front of the AfrikaBot to act like whiskers on an insect. Parallax wheel encoders [33] give precise control over wheel rotations; one learner using this system achieved an excellent time through the maze at seventeen seconds compared with an average time of 24 seconds at the time of writing. For participants who require more sophistication, Parallax ultrasonic sensors may be implemented [34]. For engineering undergraduates with the financial means laser mapping and obstacle recognition may be implemented.

There are various ways to complete the chassis of the AfrikaBot. Glued LEGO blocks [35], Meccano and Lego Technic beams held together with M3 nuts and bolts are all possible, a STL file for 3D printer is available [36] and a DXF file for those with access to a CNC machine [37].

An electronics grade soldering iron is required for participants that decide to build the robot, in the AfrikaBot outreach programme a soldering iron designed for a costly 24 volt temperature control base station is wired instead to a cheap 12 volt 1 amp transformer. This is a cost effective solution that prevents damage to the PCB that can result from an excessively hot iron. The AfrikaBot can be assembled on a classroom table with just the abovementioned soldering iron (USD $10), long nose pliers (USD $5) an electronics side-cutter (USD $5) and dual (star and flat) tip screwdriver (USD $3).

C. *Educational design and software*

The AfrikaBot challenge is a powerful educational tool, teaching the basics of industrial control and automation engineering in an innovative way. During the assembly process, teenagers learn about electronics as they solder small parts onto a single-sided PCB.

Putting the robot into the maze teaches computer programming with the graphical software. Text code programming teaches more advanced tasks that incorporate feedback and sensing mechanisms. Mechanical devices such as hobby-type servo motors expose learners to the world of mechatronics.

The free GUI software [38] offers six robot maneuvers, being forward, reverse, left and right turns, and pivot left and pivot right. The duration of the maneuvers can be varied. Learners have demonstrated they can program the robot to navigate the maze in just under twenty seconds using just the GUI software, without any sensors on the robot. An advanced GUI software feature enables basic sensors on the robot.

Once participants have mastered the graphical software, they can migrate to the one-step write-and-compile text code editor that has inbuilt syntax checking and error messages that help novices learn text code programming [39]. A key component of text code programming is logical flow, and the AfrikaBot programme imparts this knowledge at various levels.

The first learning challenge for AfrikaBot participants is how to build the robot. The second is to master the graphics and text programming software; and the third challenge is to ensure that the robot is balanced with the drive wheels positioned close to the centre of gravity and ensure that the weight over the castor ball wheel is minimal so it does not pull the robot off course. Problem solving skills are developed at every stage.

The Boe-Bot comes with a strong educational reference library in PDF format [40] that can be downloaded and printed for disadvantaged learners with limited access to computers.

The Parallax Basic Stamp 2 remains popular since it is so easy to learn to code when compared with other systems like Arduino. Despite the simplicity of the programming, it is capable of performing many useful control and automation functions, and has well-documented online support forums. The training, written by leading engineering educators in the USA, provides detailed and simple explanations on programming in text code; the operation of microcontrollers and sensors; data logging functions and even green energy management.

As learners build the rapid prototyping microcontroller electronics board, they learn about transistors, capacitors and resistors and how they work. All the resources to create a STEM program with AfrikaBot are available free on the internet [41]; videos document every aspect of how to make the robot [42].

Training for the AfrikaBot challenge is structured in a way to ensure that every participating learner gets information about the opportunities available to graduates with engineering skills, and the importance of excellent mathematics and science grades for university admission. In addition, each trainee who has participated in the AfrikaBot STEM outreach programme will have a good understanding of what microcontrollers can be used for, and the potential to start a business if one develops an embedded system.

The AfrikaBot programme teaches problem solving through a systematic and thorough approach and is an excellent educational tool for STEM teachers [43]. Schools from higher income areas, and privately funded schools, are also encouraged to participate in AfrikaBot through the creation of engineering clubs. Once a school has an active engineering club, the RobotScience project can offer support and training to aid participation in the AfrikaBot challenge [44].

IV. EARLY RESULTS FROM AFRIKABOT

The AfrikaBot challenge is a new STEM outreach programme in South Africa, and will require several years to mature into the leading STEM outreach in Africa. With increasing support from private companies and industry associations, larger numbers of learners will benefit.

Early results from AfrikaBot are reflective in nature. As an example, a learner at a recent training workshop indicated that she had developed an interest in learning how to build a walking robot. At the start of the program, the same learner indicated that she had not decided on her future choice in career, but after being exposed to role models and a field trip to an aircraft manufacturing company [45] she had become interested in engineering. The value of participating in a STEM program such as AfrikaBot will be revealed when surveys of undergraduates confirm exposure to outreach programs influenced their decision to study engineering.

In future years it is expected the effect of including young women in STEM activities like the First Avenue Institute Girls Winter Camps will play a role in creating greater gender diversity in engineering programs.

V. CONCLUSION

One of the most pressing issues facing developing countries remains the quality of education in STEM subjects. In the 2014-2015 Global Competitiveness Report, South Africa was ranked low in mathematics and science education [46].

Reasons for poor results in STEM subjects may include a shortage of well-qualified and financially-incentivised teachers, funding for school infrastructure; and the cost of STEM apparatus. The AfrikaBot challenge intends to broaden access to higher education in engineering and related technical disciplines by considering cost and simplicity in its design specifications. Hence, every aspect of the AfrikaBot design has been carefully considered to enable learners to assemble the robot with ease and access to only a few hand tools. The ruggedness and simplicity of the AfrikaBot controller, the ability to build everything oneself, the easy-to-learn free software and extensive documentation make this platform ideal for STEM education in South African schools and disadvantaged communities in Africa and around the world.

Integration of the AfrikaBot STEM program into schools in poorer communities requires involvement by lecturers and support staff from universities, private companies and interested private individuals and volunteers. The comparatively low cost of AfrikaBot offers robotics at a reasonable cost and makes it an attractive financial proposition that can also be used by a school to educate its learners with STEM activities. AfrikaBot is also an attractive option for parents, since it is affordable and it presents a potential career that will lead to financial independence for their children. Having an engineering or robotics club at the school is convenient and more cost effective than seeking private classes elsewhere.

AfrikaBot is in its inception phase and as such has not yet been integrated into high school curricula. However, every effort is being made to ensure that in the future this type of training will be incorporated in high school pedagogy.

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